UPPER ATMOSPHERES AND DIAGNOSTIC MEASUREMENTS

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DR. DONALD HUNTEN: As well as the somewhat sophisticated questions mentioned by Dr. Owen, we should also ask elementary ones like: What really are the temperatures in the atmosphere of these planets and satellites? Also, the question of the basic composition which, we are sure for the planets, is dominantly hydrogen and helium with the helium about ten percent by number or twenty percent by mass with the hydrogen; but, we don't even know that for sure, and we would like more assurance than we have at the present.

So even a mission which did nothing but measure a good, credible, and non-controversial temperature profile and measured the ratio of hydrogen to helium would be very valuable scientifically. Of course, most of us would hate to stop at that point, but we must keep reminding ourselves that the most basic questions of all are still in great doubt.

Figure 2-9 was kindly supplied by my colleague Dr. Lloyd Wallace; it is from a paper by Wallace, M. Prather, and M. J. S. Belton, in press in the Astrophysical Journal. Curves (a) - (e) were calculated on the basis of radiative thermal equilibrium, the inputs being solar and planetary radiation. (Note that pressures run from one (1) bar to one (1) microbar, so that this region is the stratosphere and mesosphere.) Owen's and Lewis' talks refer to the region below this figure.

Curve (e) is the hottest that could be obtained with purely radiative heat inputs, and it falls far short of the curve from Pioneer 10, the one without a label. The more recent data, presented this morning by Kliore, carry these temperatures even higher at deeper levels.

The upper part of the figure shows several computed curves, and also several sets of data from the occultation of the star Beta Scorpii, observed and reduced by different people. Although there is an appreciable spread, the agreement is reasonable, and so is the agreement with the calculated temperatures, especially the preferred curve (a). These temperatures are warm, 160-180°K, though nowhere near as warm as the ones from Pioneer.

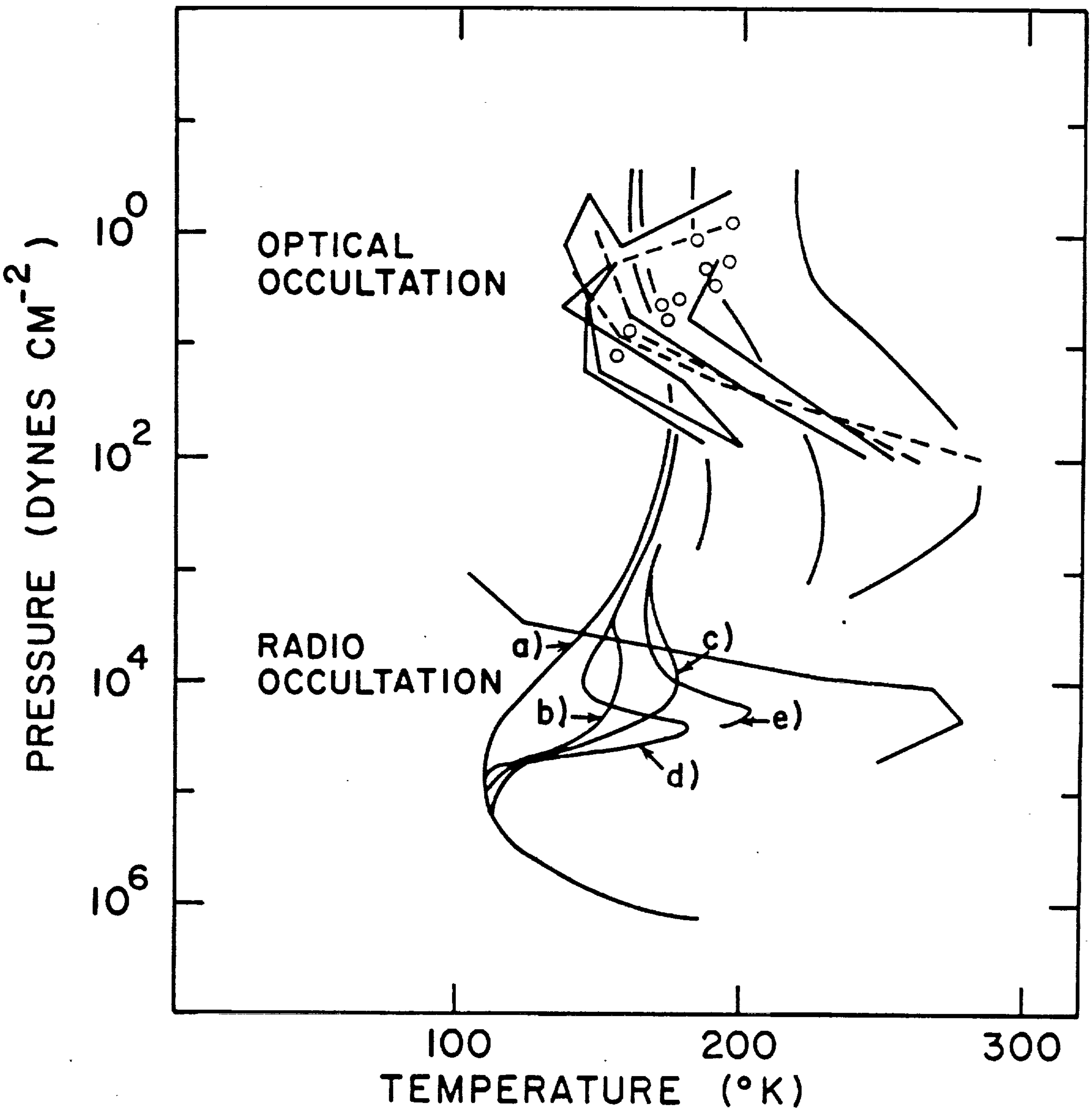
OPTICAL
OCCULTATION
RADIO
OCCULTATION
a)
b)
c)
d)
e)
10^0
10^2
10^4
10^6
PRESSURE (DYNES CM^{-2})
100
200
300
TEMPERATURE (°K)

Figure 2-9

One would be tempted to say that the optical data are good and that there is some unknown factor perturbing the radio data. But the two methods are based on very similar physical principles, and it is hard to see why one, and not the other, should be rejected. For now we have to conclude that there is something fundamental that we just do not understand. It is not just a matter of the disagreement shown in Figure 2-9. As Owen already discussed, there are several ways of deducing the temperature in the 1-bar region: thermal emission (also measured by Pioneer 10), spectroscopic line strenghts, the presence of clouds. They all agree and the temperature they agree on is 100-130°K, just what is computed. Thus, we have a conflict between data from different sources, not just between observation and a calculated model.

So, simply a probe carrying a thermometer and nothing else would resolve a very fundamental question about the basic nature of the Jovian atmosphere. Of course, if we have this problem that we can't understand Jupiter, there is no basis for suggesting that we understand any other atmospheres in the outer solar system either.

Many of you have been involved in studying candidate missions based on the set of experiments (Figure 2-10) which is sort of a minimum or basic payload, which has been in use for the last few years. It is based on the thinking and experience that we have had so far with the Pioneer Venus probe mission, but it is cut down considerably.

From Owen's description of the atmosphere and the scientific questions, you can see that the measurements on the right are all useful and important.

Properly speaking, the main clouds visible from Earth are in the lower atmosphere and therefore, not really the province of this talk. On the other hand, there is lots of reason to believe that there are clouds, or at least haze, far up into the stratosphere; and this is basically because the atmospheres of Jupiter, Saturn, and Titan are all dark in the ultraviolet. A gaseous atmosphere has no business being dark in the ultraviolet because it scatters; it should be a blue sky, to put it as shortly as possible. It should exhibit rayleigh

FIGURE 2-10

BASIC PAYLOAD

THERMOMETER	TEMPERATURE
BAROMETER	PRESSURE
ACCELEROMETER	DENSITY
	TURBULENCE
MASS SPECTROMETER	COMPOSITION
NEPHELOMETER	CLOUDINESS

FIGURE 2-11

OPTIONS

COMPOSITION BY GAS CHROMATOGRAPH
CLOUD PARTICLE SIZE SPECTROMETER
SOLAR RADIATION FLUX
THERMAL RADIATION FLUX

scattering, to say it in a more scientific manner, and have a higher and higher reflectivity at shorter wavelengths until something starts to absorb. That something has to be methane which doesn't absorb above 1500 or 1400 angstroms.

So, something else is absorbing strongly at wavelengths as long as 3,000 or 3,500 angstroms at very high altitudes in all these atmospheres. The accepted explanation is a fine, absorbing aerosol, or dust, as proposed by Axel (Astrophys. J. 173, 451, 1972). This material is probably related to some of Owen's later figures; presumably there are photochemical products, photochemical smogs if you like, produced by the action of solar radiation mostly on methane and then a slow fallout of the particles to lower levels. It could be regarded as asphalt, or tar, or gasoline. I think those colorful names for this colorful substance give you the general idea.

Returning to Figure 2-10 we show, as we have for Pioneer-Venus for many years, a mass spectrometer as the basic instrument for measuring composition. That should be excellent for getting the hydrogen-to-helium ratio; it should be reasonably good for getting methane and ammonia. But a mass spectrometer isn't really very well suited to measuring other, more subtle things, and in particular photochemical products, chromophores, and so on. One really has to question whether anything is very suitable, considering the extremely small abundance that we have to be dealing with.

However, one should at least consider options like those shown in Figure 2-11 which are, again, based on Pioneer-Venus experience. The mass spectrometer is probably essential in order to get major gases and unexpected constituents. But the gas chromatograph has a lot to be said for it, particularly for chemically active and rather minor constituents. We have a promising gas chromatograph on Pioneer-Venus at the moment and there is no reason why it shouldn't work in the outer solar system as well. It should be considered a prime candidate to supplement the mass spectrometer.

Instead of or in addition to a nephelometer, there is the possibility of a cloud-particle-size spectrometer, a shadowgraph device that measures the shadows of particles as they go through a laser beam. Again, this is a Pioneer-Venus experiment. We would like to know the flux of solar radiation, namely the difference between the up-going and down-going radiation in the visible and neighboring wavelengths and, similarly, for thermal radiation. Now, one wouldn't have considered those last two measurements too important until recently but, again, I must stress that we are absolutely baffled by the problem of the thermal structure of the Jovian atmosphere. We thought we understood it; we could fit all the spectroscopic and thermal data we had, beautifully really, by computed thermal structures. And then along comes this radio measurement from Pioneer 10 which disagrees by orders of magnitude. When I say orders of magnitude I'm thinking of the fact that thermal radiation goes as the fourth power of the temperature. A factor of 3 in temperature means a factor of 81 in thermal radiation.

Before I close, I would like to say a few words about the rest of the upper atmosphere, namely the thermosphere and ionosphere. There again, we have the example of Pioneer Venus, although there is a major difference because at Venus we will have a low-periapse orbiter. I would hope that an attempt would be made to take pre-entry measurements of at least neutral and positive-ion composition. Even a few measurements can be of great value, because we are looking for large effects. Different ionospheric models often disagree completely on which positive ions are present. The whole nature of the upper atmosphere is determined by diffusive separation of light and heavy constituents. The homopause, the level at which this effect begins, can be determined by comparing measurements of two or more gases made before and after entry. In fact, we already have an estimate of the homopause level for Jupiter, based on the Lyman-α measurements on Pioneer 10 by Judge and Carlson. The density seems to be between what we find on Earth and what we think exists on Mars. We can, therefore, make models of Jupiter's upper atmosphere with much more confidence than we could before.

But what about Titan? The question of what measurements to make there was considered briefly by the Titan Atmosphere Workshop last year. It is obvious that one is dealing with a very different atmosphere, one that is much richer in heavier molecules and poorer in the lighter ones, hydrogen and helium. Although we don't expect helium and the amount of hydrogen is in doubt, we probably still have to fly the mass spectrometer. The gas chromatograph, however, very clearly becomes the primary composition experiment for Titan.

The real question, still, about Titan is whether it has enough atmosphere so that we can really hope to probe it with the technology that we're talking about. There were somewhat wild ideas around a year ago that the surface pressure on Titan might be as great as a thousand atmospheres, if you really call it a surface, and pressures of half to one atmosphere were very respectable indeed. They are still respectable, but the strength of the evidence, as we see it, for such high pressures is much less than it was. When we were really pinned down at the Titan workshop to set an absolute minimum surface pressure, the value we could give with confidence was embarrassingly small, about 20 mb. The engineering information available at the time suggested that an entry probe might not yet be on the parachute at that level. If so, the mission is not attractive. Both scientists and engineers must work on this problem: what is the lower bound to the surface pressure, and what minimum pressure is needed for a viable mission. We have a few years yet, and progress is rapid already; hopefully, both sets of answers will be available by the time they are needed.

MR. LOU FRIEDMAN: I was interested in the remark about haze in the upper atmosphere. Are there any analogies with the MVM findings on Venus and similar photochemical haze?

DR. HUNTEN: Well, I dare say it is an analogue in a sense; we have such a haze in our own stratosphere too, and it's chemically very similar to the haze and maybe even the main cloud deck on Venus. So, I think we have to get more and more used to the fact of life than atmospheres are typically quite dirty; especially atmospheres that aren't frequently cleansed by rainstorms. Maybe the Earth's atmosphere is the major anomaly, because rain is so prevalent here and washes things out of the atmosphere. But, in terms of the details of what the haze is made of, I don't think it is safe to draw a close analogy; just the general principle that it's a photochemical haze.